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ABSTRACT

We describe a technique for controlled metamorphosis between surfaces in 3-space. We apply well-understood techniques to produce shape metamorphosis between models in a 2D parametric space. The user selects morphable features interactively, and the morphing process executes in real time on a high-performance graphics multicomputer.

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1 Introduction

Image metamorphosis (morphing) is a powerful and easy-to-use tool for generating new 2D images from existing 2D images. In this paper we describe a new technique of interactively applying feature-based metamorphosis to surfaces in 3-space.

Wolberg [Wolberg 90] described a pointwise-correspondence technique for morphing 2D images. If a feature in image A is meant to match a feature in image B, the user chooses a point within the feature of each image. When the point morphs from A to B, so does a neighborhood surrounding it.

Beier [Beier 92] described a segment-correspondence technique for morphing 2D images. When a feature in image A is meant to correspond to a feature in image B, a line segment is drawn over the feature in each image. As the segment morphs from A to B, so does a neighborhood surrounding it. By judiciously creating line segments, the user can preserve all the important features throughout the morph.

Kent [Kent 92] described a method for morphing 3D polyhedral objects. New vertices, edges, and faces are added to each object so that every polygon of the first object corresponds to a polygon of the second. To morph between them one interpolates between corresponding vertices. The user can exercise some control over how the correspondences are established, but only indirectly. Kent concludes:

... techniques that provide a finer level of control over the transformation are needed. One possibility is to add a warping step ... before the topologies are merged.

We implemented Beier's technique as that warping step, warping the model's 2D parameter space rather than the model's projected 2D image.

2 Our Technique

Our method consists in morphing the 2D parameter space of a pair of surface models. We use Beier's techniques to accomplish the warping. The 2D nature of the process makes interaction easy. We can simultaneously present to the user both the parametric pre-image and the resulting surface in 3-space to assist in defining the features to morph.

We begin with a pair of surface models A and B (Figure 1) which have been meshed over some parameter space. Models in other formats (like polygon-lists, NURBS, or implicit surfaces) must be resampled and meshed so that they have similar parameter spaces. This may seem like a relatively harsh restriction, making the technique applicable only to convex or star-shaped objects. However, there are physically-based and model-specific projection techniques [Kent 92] that can be applied to more complex geometries.

The surface attributes of the source models must be available in the 2D parameter space so that they may be interpolated. There are map-parameters attached to each sample as well. For

example, in the case of a spherically-projected apple the map-parameter is the radius at each sample point. Knowing the radius, one can reconstruct the surface of the original apple and attach the sample's surface attributes to it.

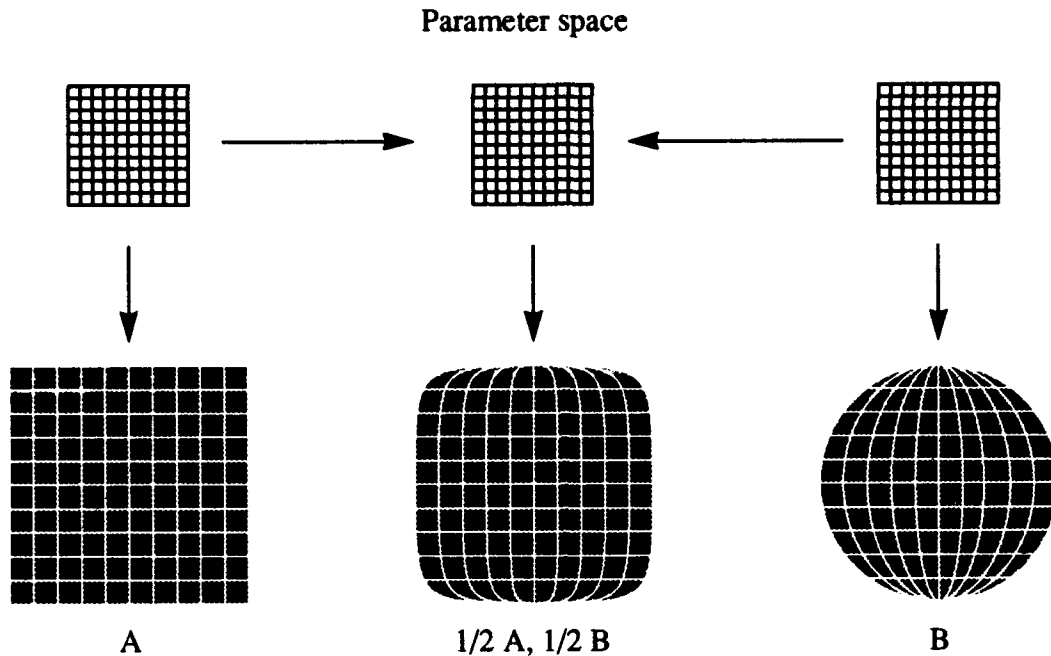


Figure 1. Object A (on the left) is morphed into object B (on the right.) The two objects are parametric surfaces. To interpolate between the geometries, one can interpolate between the 2D parameter spaces.

The surface attributes are interpolated as well as the geometries. The samples' map-parameters are also interpolated since they serve to construct the target model from a morphed pre-image in the 2D parametric space. The 3D target model is derived from this pre-image by applying the mappings; in doing so, we use the "morphed" values of the map-parameters at each sample point.

3 Interactive Implementation

We implemented a prototype system on the Pixel-Planes 5 graphics multicomputer, a heterogeneous system consisting of over 30 Intel i860-based MIMD nodes and many thousands of SIMD pixel-processors. We chose Beier's technique for its easy and intuitive control methods. We have demonstrated our method on 3D models of human heads generated by a 3D scanner (Cyberware). These models are represented in cylindrical coordinates (with the mantle of the cylinder serving as the 2D parameter space for the morphing process). Our samples contain the surface attributes of color and radius. Traditional morphing between 2D images operates on color as a function of

2D pixel coordinates; here we operate on color as a function of 2D parametric coordinates, and on the map-parameter of radial distance.

The software design of the prototype system is straightforward: the 2D parameter space of each model is replicated on all MIMD nodes. Each node generates a subset of the morphed pre-image. The nodes then apply the morphed map-parameters to generate polygons from the morphed pre-image.

Figures 2a and 2b show the 2D pre-images on which a user has marked features. Figure 2a shows the color intensity of the models in the parameter space of cylindrical coordinates. Figure 2b shows the radius function (essentially a height function) in cylindrical coordinates, mapped to grey intensity values. Note the pairs of line segments: they establish correspondences between various features of the two source models. These features may be chosen simply by their similar color (like matching the red regions of lips in a 2D image), but also by their similar 3D geometry (like matching the pointed tip of each nose). This latter ability is crucial for matching features in regions of constant color. These features are prominent in profile, but not in the general projected views. It would be inefficient to search for corresponding features by continually rotating the objects until their features are identifiable by their colors alone.

Figure 3 shows a sequence of shape metamorphosis generated by our system. Mapped onto the surfaces of the 3D models, the line segments become surface-following curves. The face rotates as it is morphed to demonstrate how the geometric features are preserved during the interpolation. Notice, for example, how the lips spread open as the morphing progresses. Notice also that one of the eyes is obscured in the left image. Pure image-based morphing cannot interpolate between features when one of them is obscured under a particular viewing projection.

The entire process of matching features and warping between the surfaces in Figure 3 takes about 5 minutes for an experienced user. The 274x222 surface mesh is morphed and rendered on Pixel-Planes 5 at 20 frames per second (4x4 decimation) or at 1 frame per second (full resolution).

4 Conclusions

We have described how to apply image-based metamorphosis to parametrically-defined surfaces. When a surface is defined parametrically, our method of metamorphosis is superior to ordinary image-based warping: the warp is defined only once (rather than frame-by-frame) for an animation. Consequently it can be accomplished in a single short interactive session. For a parametric surface, our method is also superior to existing techniques that automatically map between surfaces in a global manner. The user interactively defines which individual features on the first surface correspond to features on the second one. The gradual morphing is itself simple and parallelizable. The interpolating surfaces can be constructed and displayed at interactive or even real-time frame rates.

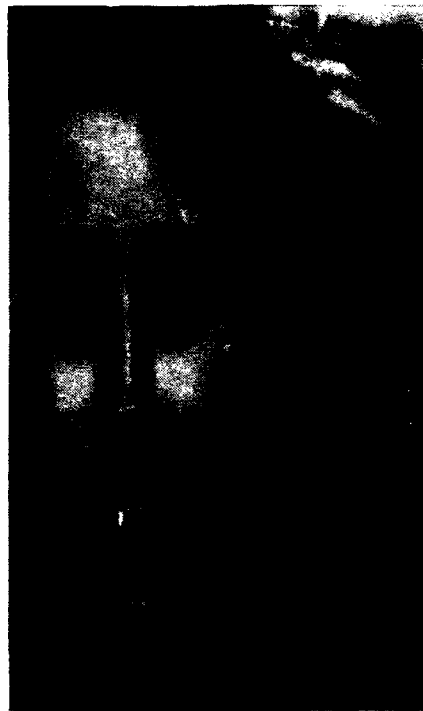
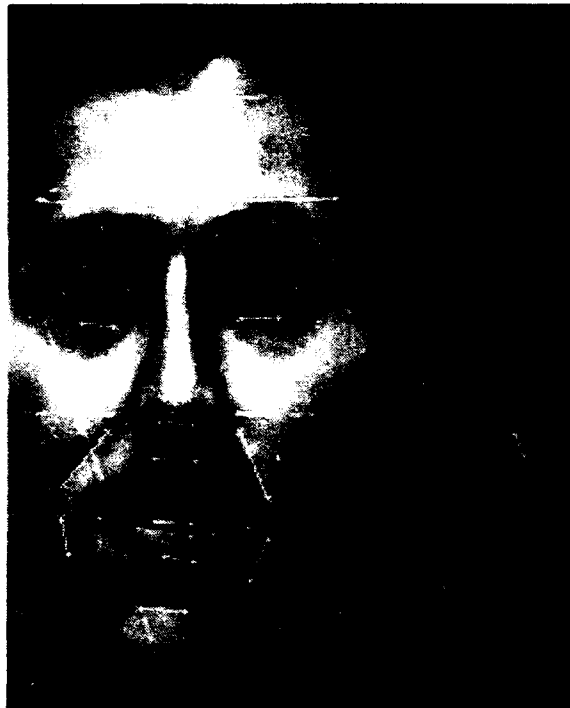


Figure 2a. Line segments define similar features in two models of human heads. The greyscale image represents intrinsic color.



Figure 2b. Line segments define similar features in two models of human heads. The greyscale image represents radial distance in cylindrical coordinates.



Figure 3. Metamorphosis of surface shapes in 3-space. Top row: 0% and 33% versions of the David -> Heidi metamorphosis sequence. Bottom row: 67%, and 100% versions of the David -> Heidi metamorphosis sequence

References

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- [Wolberg 90] G. Wolberg, *Digital Image Warping*. IEEE Computer Society Press, 1990.

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